# LARGE ANTENNA EXPERIMENTS ABOARD THE SPACE SHUTTLE -- APPLICATION OF NONUNIFORM SAMPLING TECHNIQUES

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ABSTRACT

Future satellite communication and scientific spacecraft will utilize antennas with dimensions as large as 20 meters. In order to commercially use these large, low sidelobe and multiple beam antennas, a high level of confidence must be established as to their performance in the 0-g and space environment. Furthermore, it will be desirable to demonstrate the applicability of surface compensation techniques for slowly varying surface distortions which could result from thermal effects. In this paper, an overview of recent advances in performing rf measurements on large antennas is presented with emphasis given to the application of a space based far-field range utilizing the Space Shuttle and the concept of a newly developed nonuniform sampling technique.

## 1. INTRODUCTION

It is very likely that antennas in the range of 20 meters or larger will be an integral part of future satellite communication and scientific spacecraft payloads. For example, Fig. 1 depicts the conceptual evolution of the Land Mobile Satellite System which is anticipated to evolve from utilizing approximately 6-9 meter reflectors to 55 meter reflectors in the era spanning the late 1980's to early 2000. In order to commercially use these large, low sidelobe and multiple-beam antennas, a high level of confidence must be established as to their performance in the 0-g and space environment. Certain ground (1-g) testing can be performed to validate the workability of different segments of such large structures; however, it will be a formidable task to characterize the performance of the entire structure on the ground. For this reason, a conceptual study has been initiated with the intention to describe an experiment aboard the Space Shuttle to demonstrate the deployment reliability of the antenna

structure, to measure thermal and dynamic structural characteristics, and to verify performance specification under all expected conditions. In particular, special consideration is being given to the rf far-field pattern measurements which should provide the ultimate characterization for the antenna performance (Fig. 2).
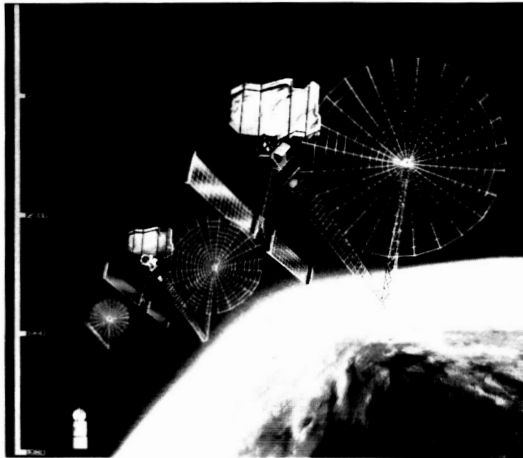


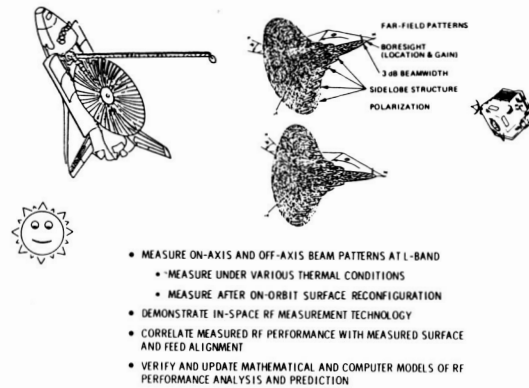FIG. 1. Evolution of the proposed Land Mobile Satellite System (LMSS).

FIG. 2. Spaced-based rf experiment objectives aboard the Space Shuttle.

Several potential scenarios have been considered and the relative merits of each of them are shown in a qualitative manner in Fig. 3. Among all these possibilities the application of the scenario shown in the last row appeared most feasible. The rf experiment is anticipated to be performed on a 20-meter offset reflector at L-band using the Remote Mini-Flyer, a NASA-developed reusable and retrievable spacecraft (a modified Spartan), as the carrier for an rf beacon. This beacon is used to illuminate the antenna in a similar fashion as one does in the ground-based far-field ranges using transmit illuminators. An artist's rendition of this space-based experiment is depicted in Fig. 4.

## 2. RF MEASUREMENT CONSIDERATIONS

In order to reduce the cost of the experiment, it has been anticipated that no gimbal mechanism will be used to accurately control the position of the antenna with respect to the illuminator. Instead, the relative motion of the Shuttle and free-flier in a controlled manner will be utilized to provide the angular range of interest. Depending on what the exact covered u-v space will be, several scenarios could be considered. The schematics of two possible measurement scenarios are shown in Figs. 5 and 6.

Since without any gimbal system it will be impractical to measure antenna patterns in specified $\phi$ cuts, one may

have to perform the measurement in a specified u-v angular range in a time period in which the antenna structure is not changed appreciably from an rf viewpoint. Fig. 5 shows the possibility of measuring very dense but nonuniformly measured data points from which the needed $\phi$-cuts or contour patterns can be constructed. If it is proven that the possibility of measuring a very dense set of data may not be realistic, an alternate scheme should be available. This alternate scheme is depicted in Fig. 6, which assumes that the measured amplitude and phase are obtained at relatively sparse and nonuniformly distributed u-v points. The question is, then, whether or not one can construct the $\phi$-cuts from a set of nonuniformly distributed measured data points.



| TECHNIQUES | CONFIGURATION | COMPLEXITY | USEFULNESS | COST |
|---|---|---|---|---|
| NEAR FIELD TECHNIQUES | | 😦 | 🙂 | 😦 |
| COMPACT RANGES | | 😧 | 😐 | 😦 |
| BEACON ON THE GROUND | | 😐 | 😦 | 😐 |
| RECEIVING CITIES ON THE GROUND | | 😐 | 😦 | 😐 |
| RADIO STAR SOURCES | | 🙂 | 😐 | 🙂 |
| GEO SATELLITE SOURCES | | 🙂 | 😐 | 🙂 |
| FREE-FLYER AS A BEACON | | 🙂 | 🙂 | 😐 |

FIG. 3. A qualitative comparison of different measurement techniques aboard the Space Shuttle.
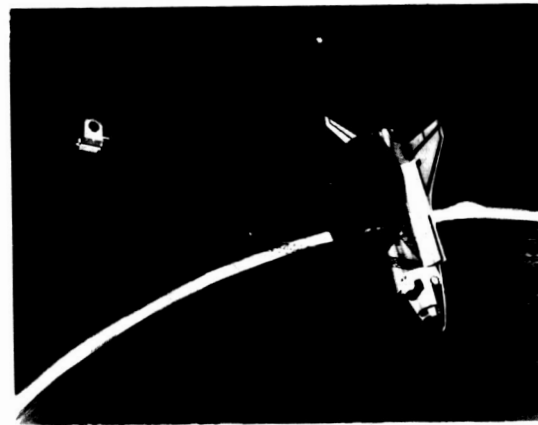


FIG. 4. An artist's rendition of the proposed large antenna Shuttle experiment.
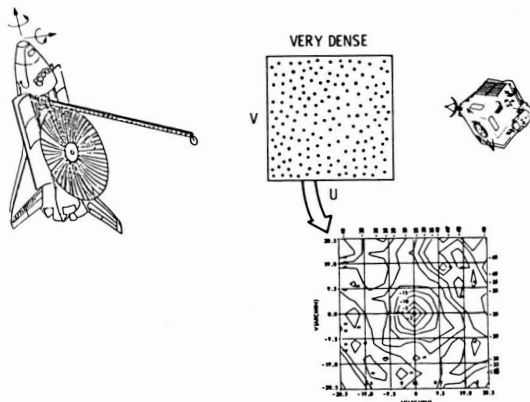


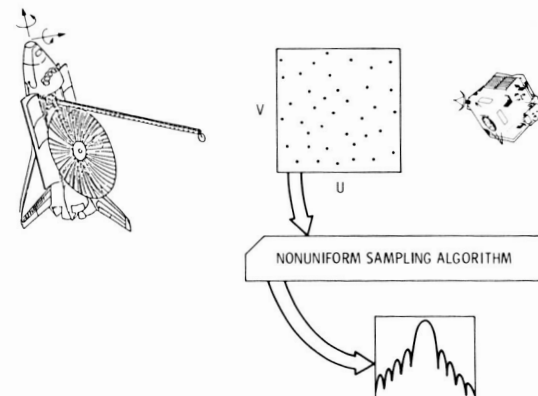FIG. 5. Schematic of nonuniform and very densely measured sampled points.



FIG. 6. Schematic of nonuniform and relatively sparsely measured sampled points.

Recently, Rahmat-Samii and Cheung [1] have demonstrated that a two-dimensional nonuniform sampling technique which utilizes irregularly spaced samples (amplitude and phase)

can be used to generate the far-field patterns. The mathematical developments of this two-dimensional nonuniform sampling technique have been detailed in [1]. Additionally, a powerful simulation algorithm has then been developed to test the applicability of this sampling technique for a variety of reflector measurement configurations [1]. For example, Figs. 7 and 8 show the simulated nonuniform sample points and the reconstructed far-field patterns in specified $\phi$-cuts for a 20 meter offset reflector antenna with a defocused feed operating at L-band [1]. In Fig. 8, the solid curves are reconstructed co-polar and cross-polar patterns using the nonuniform sampling technique. It is noted that even though no sample points are captured in these cuts, the reconstructed patterns agree well with the ideal patterns in the angular range where the nonuniform sample points have been generated, i.e., ±3.2 degrees. Many tolerance studies have also been performed to demonstrate the required measurement accuracies in applying the nonuniform sampling technique [1].
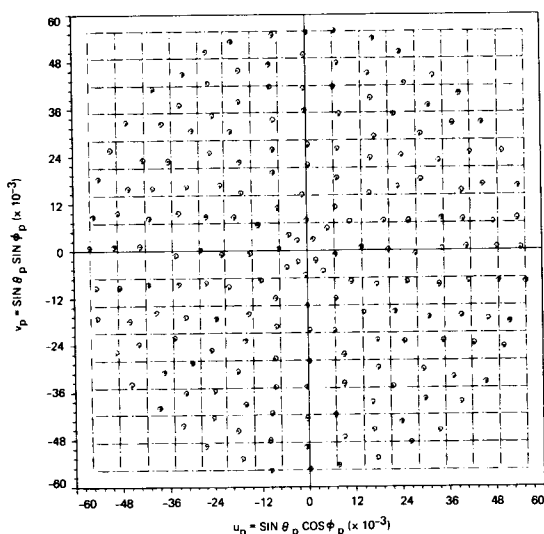


FIG. 7. One hundred ninety two nonuniform sampled point distribution in (u,v) coordinates which covers an angular region of $\theta$ = ±3.2 degrees.



FIG. 8. Reconstructed far-field patterns from 192 sampled points using nonuniform sampling technique.

To validate the accuracy of the nonuniform sampling technique for antenna pattern construction, several measurements have been performed as reported in [2]. In one of the measurements JPL's 1200-ft far-field range was used, where a 1.47-m circularly polarized Viking reflector antenna [3] (Fig. 9) was measured at X-band (8.415 GHz) using a corrugated horn as the illuminating antenna. The far-field amplitude and phase were measured in the directions shown in Fig. 10 which consisted of 585 nonuniformly distributed sampled points in (u,v) coordinates.
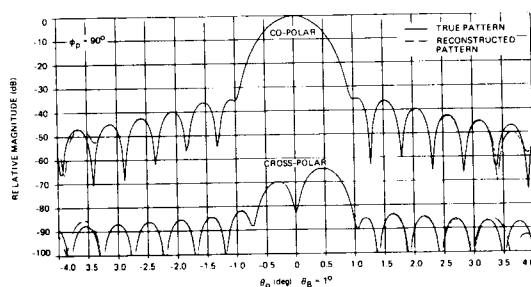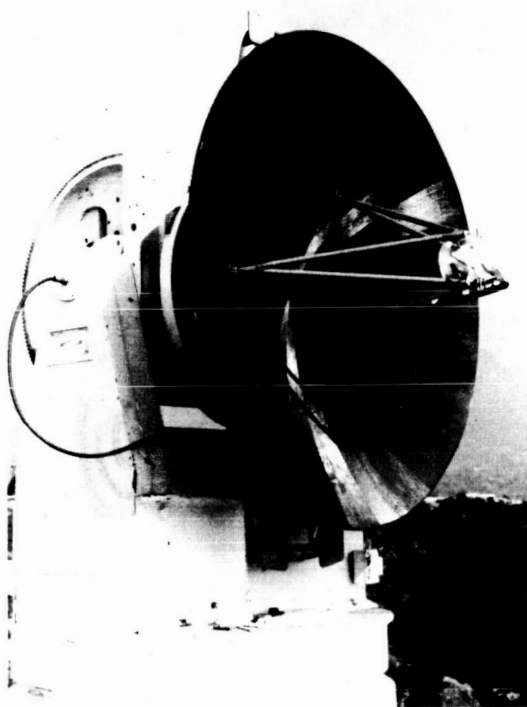
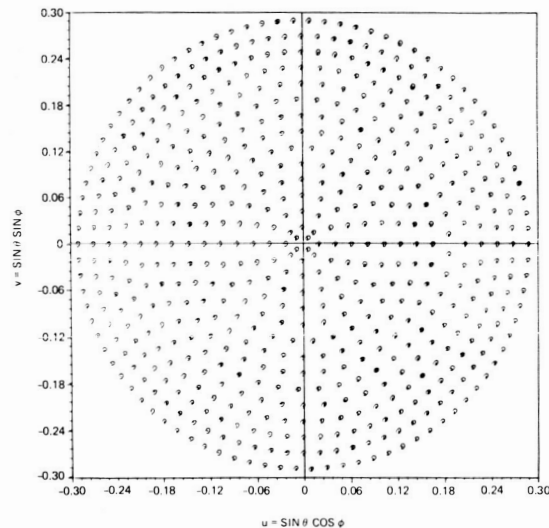FIG. 9. The 1.47-m circularly polarized Viking reflector antenna operating at X-band (8.415 GHz).



FIG. 10. Five hundred eighty five measured data point distribution in (u,v) coordinates which covers an angular region of $\theta = \pm 16.8$ degrees.

The total system errors for amplitude measurement have been estimated to be less than 0.2 dB at -40 dB level relative to the boresight power level and the phase measurement error has been within $\pm 5$ degrees. The pointing accuracy has been estimated to be better than $\pm 0.1$ degrees. The co-polar far-field patterns for $\phi = 90$ degrees are depicted in Fig. 11. The solid curves are the standard azimuth cuts and the dashed curves are the reconstructed patterns using the nonuniform sampling technique. These patterns are constructed by utilizing the window concept as discussed in [1,2]. Note that asymmetric patterns have resulted even though a symmetric reflector was used. This is due to the feed and strut blockage effects. In the angular range of $\pm 16.8$ degrees where the measured data are available, the comparison between the solid and dashed curves demonstrates close agreement. Note that even though no sampled point has been used at the boresight, the peak of the beam has been reconstructed very well.
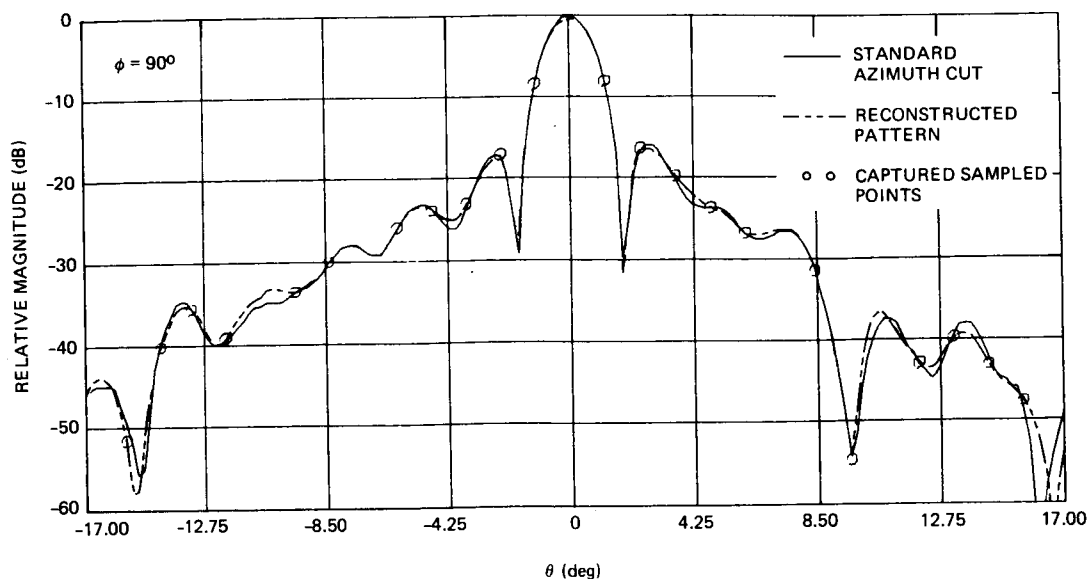
FIG. 11. Reconstructed far-field patterns of the Viking reflector at X-band using nonuniformly distributed measured data.

ACKNOWLEDGEMENTS

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1.  Rahmat-Samii Y. and R. Cheung, "Nonuniform sampling techniques for antenna applications," IEEE Trans. Antennas Propagat., vol. 35, pp. 268-279, 1987.

2.  Cheung R. and Y. Rahmat-Samii, "Experimental verification of nonuniform sampling technique for antenna far-field construction," Electromagnetics, vol. 6, no. 4, pp.277-300, 1986.

3. Rahmat-Samii Y. and M. Gatti, "Far-field patterns of spaceborne antennas from plane-polar near-field measurements," IEEE Trans. Antennas Propagat., vol. 33, pp. 638-648, 1985.